Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 75-76
6-8 December, 2010

Development and Ultrasonic Measurements of 150°C 1x16 Flexible Transducer Array

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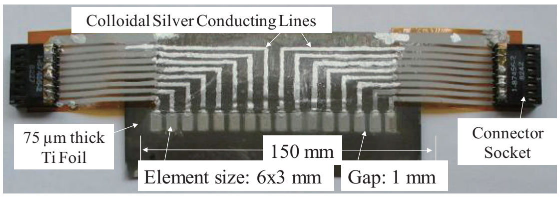
1. Introduction

Multiple ultrasonic transducer (UT) arrays [1 - 3] are becoming attractive for non-destructive evaluation (NDE) applications due to reduced inspection times compared to those that are incurred from the use of single element UTs. These are also often required to operate at high temperatures (HT) [1, 2]. In this study, the fabrication of one dimensional (1D) flexible ultrasonic transducer (FUT) arrays will be presented using a sol-gel sprayed piezoelectric thick film technology [4,5]. The ultrasonic measurements will be performed at temperatures of up to 150°C.

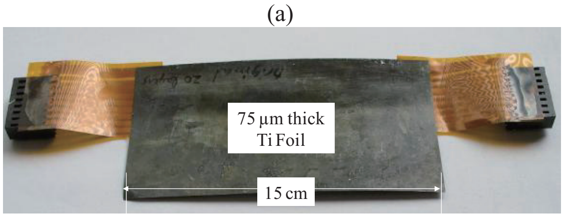
2. Fabrication of Piezoelectric 1D FUT Array

75 µm thick titanium (Ti) or stainless steel (SS) foils were used as the substrates for 1x16 1D FUT arrays. The top and bottom views of one array on a Ti foil are shown in Fig. 1a and Fig. 1b, respectively. The fabrication of the FUT array consists of six main steps [4,5]: (1) preparing a high dielectric constant lead-zirconate-titanate (PZT) solution, (2) ball milling the piezoelectric PZT powders in a PZT solution to submicron sizes, (3) sensor spraying using slurries to produce a film with thicknesses of between 5 and 20 µm, (4) heat treating to produce a solid PZT composite (PZT-c) thick film, (5) Corona poling to obtain piezoelectricity, and (6) colloidal silver spray with a mask to deposit top electrodes and electrically conducting lines. Steps (3) and (4) are performed multiple times to produce optimal film thicknesses for specified ultrasonic operating frequencies. An insulation layer is coated onto the Ti substrate under the conducting line stripes. Each element size of the 1D 1x16 element FUT array was 6 mm by 3 mm and the gap between them was 1 mm as shown in **Fig. 1a**. All the components shown in Fig. 1a and **1b** may sustain and have been tested at up to 150°C. Each of the two connector sockets is connected to eight FUT array elements and one electrical ground line which is the Ti substrate.

1x16 1D arrays fabricated on 75 µm thick SS foils with different electrical connection schemes were also made. It is noted that the signal strength of the FUTs made on Ti membrane is normally a few dB better than that achieved from FUTs made on SS foil because of a decrease in substrate oxidation during heat treatment. However, FUTs using SS foils may be brazed onto steel substrates such as pipes for structural health monitoring (SHM) purposes at HT [5]. Finally another insulation layer acting as a protection layer to prevent moisture, which may also sustain temperatures of up to 150°C was coated, but not shown in Fig. 1. The wire connection from either socket to the pulser-receiver is not presented here.



(a)



(b)

Fig.1 (a) Top and (b) bottom view of a 1x16 FUT array on a 75 µm thick Ti foil.

3. Experimental Results

Fig. 2 shows the setup for the ultrasonic measurements carried out at 150°C using a two-channel ultrasonic pulser-receiver system for element 5 and element 9 of the 1D 1x16 FUT array (starting from the leftmost element) shown in Fig. 1. The FUT array was attached to the flat surface of a 15.1 mm thick aluminum (Al) plate using a high temperature gel couplant. At 150°C, **Fig. 3a** and **Fig. 3b** show the simultaneous pulse-echo measurements for these two elements with the same data recording settings. The multiple echoes come from the multiple reflections from the top and bottom surfaces of the Al plate. The center frequencies for the 1st echo of element 5 and element 9 are 7 and 6 MHz, respectively. These results at 150°C are about 7 dB weaker than those measured at room

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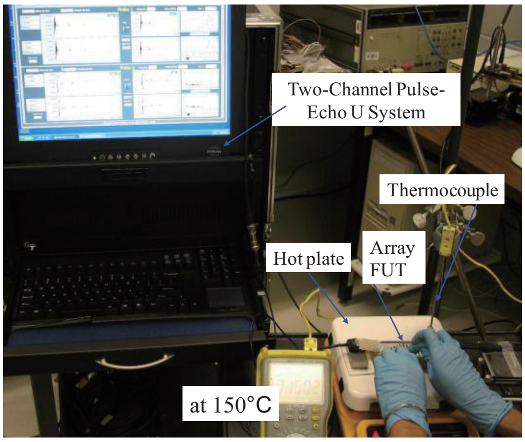
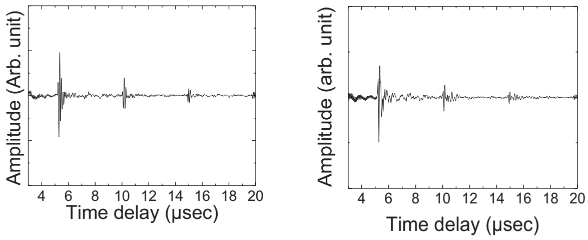


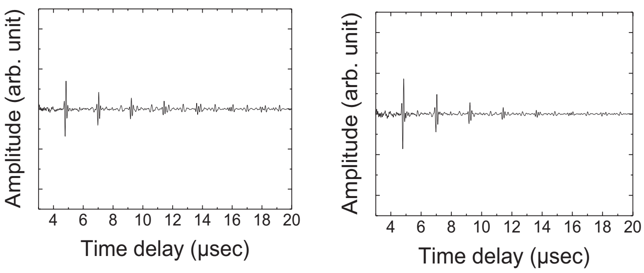
Fig.2 Experimental setup for ultrasonic measurements at 150°C.



(a) Element 5 (b) Element 9

Fig.3 Ultrasonic pulse-echo measurements at 150°C

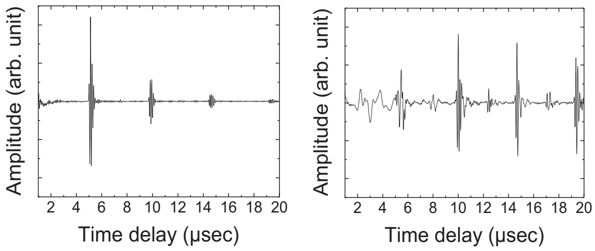
temperature. Since the FUT array is flexible, it was then attached to a steel pipe with an outer diameter (OD) of 89 mm and a wall thickness of 6.5 mm for ultrasonic measurements. **Fig. 4a** and **Fig. 4b** show the simultaneous pulse-echo measurements for the elements 5 and 9 with the same data recording settings. The multiple echoes come from the reflection from the inner surface of the pipe. The center frequencies for the 1st echo of element 5 and element 9 are 7 and 5 MHz, respectively. Since the FUT array, with its connector sockets and protection layers, has its flexibility reduced, it is preferable that it be used for NDE of a pipe when the gap between element 8 and element 9 is aligned with the pipe axis.



(a) Element 5 (b) Element 9

Fig.4 Ultrasonic pulse-echo measurements at 150°C

In order to demonstrate the feasibility of the FUT as a phase array transducer, ultrasonic measurements using pitch-catch mode on the same Al plate were performed. **Fig. 5a** and **Fig. 5b** show the results at room temperature in which element 5 was used as the transmitter, and elements 6 and 8 served as the receivers, respectively. These signals are amplified by 5 dB and 17 dB, respectively. For element 5→ 6, the time of flight of the 1st echo reflected from the bottom through a single V-path is estimated to be around 4.8 μs, and that of the 2nd echo through a double V-path is 9.6 μs. For element 5→ 8, the times of flight of the 1st and 2nd echoes are estimated to be 5.2 μs and 9.8 μs, respectively. Fig. 5 agrees with the estimation, where the discrepancy is due to the thickness of the Ti foil and the couplant under the Ti foil. However prior to these reflected echo signals, another low frequency signal is observed in Fig. 5b, which is due to the plate wave propagating along the Ti membrane. Such cross talk may be significantly reduced by cutting a groove in the gap among two adjacent elements via a high precision machining such as laser.



(a) Element 5→6 (b) Element 5→8

Fig.5 Ultrasonic pitch-catch measurements

4. Conclusions

The fabrication of 1D 1x16 FUT arrays on 75 μm thick Ti and SS foils together with wire connections has been presented. They were used to perform ultrasonic pulse-echo measurements on a steel plate and a pipe at up to 150°C. The signal strengths obtained at 150°C were about 7 dB weaker than those obtained at room temperature. A preliminary study on the pitch-catch mode using an element as transmitter and multi-elements as receivers in the FUT array was carried out.

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